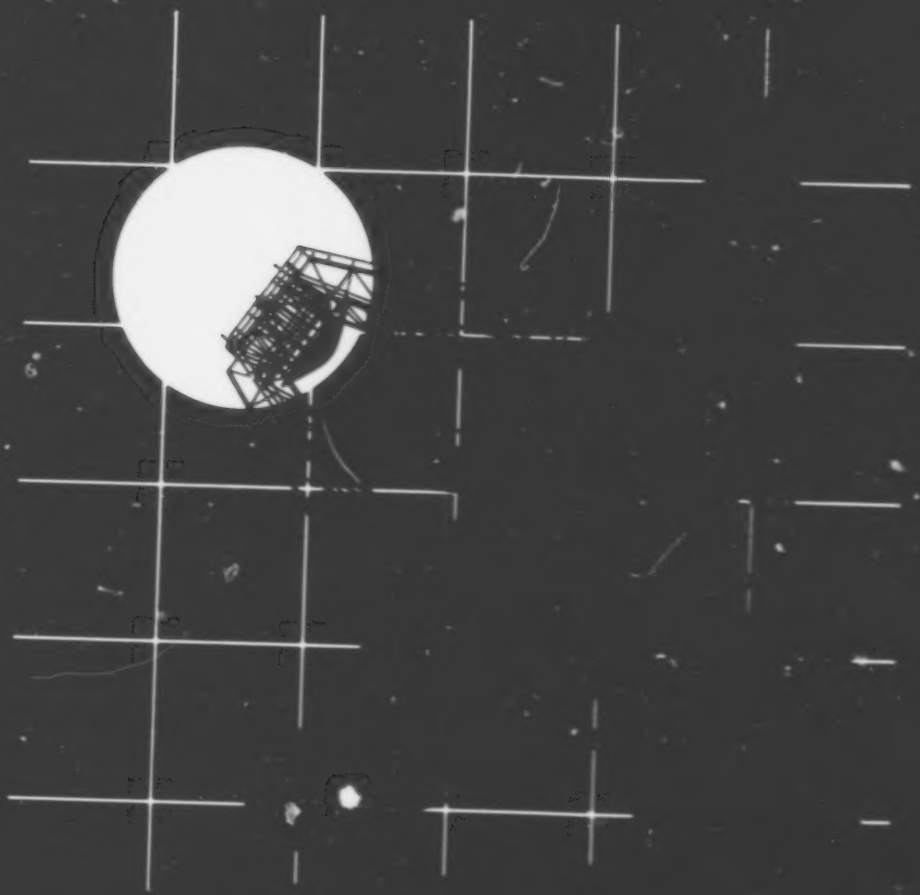

THE DEEP SPACE NETWORK

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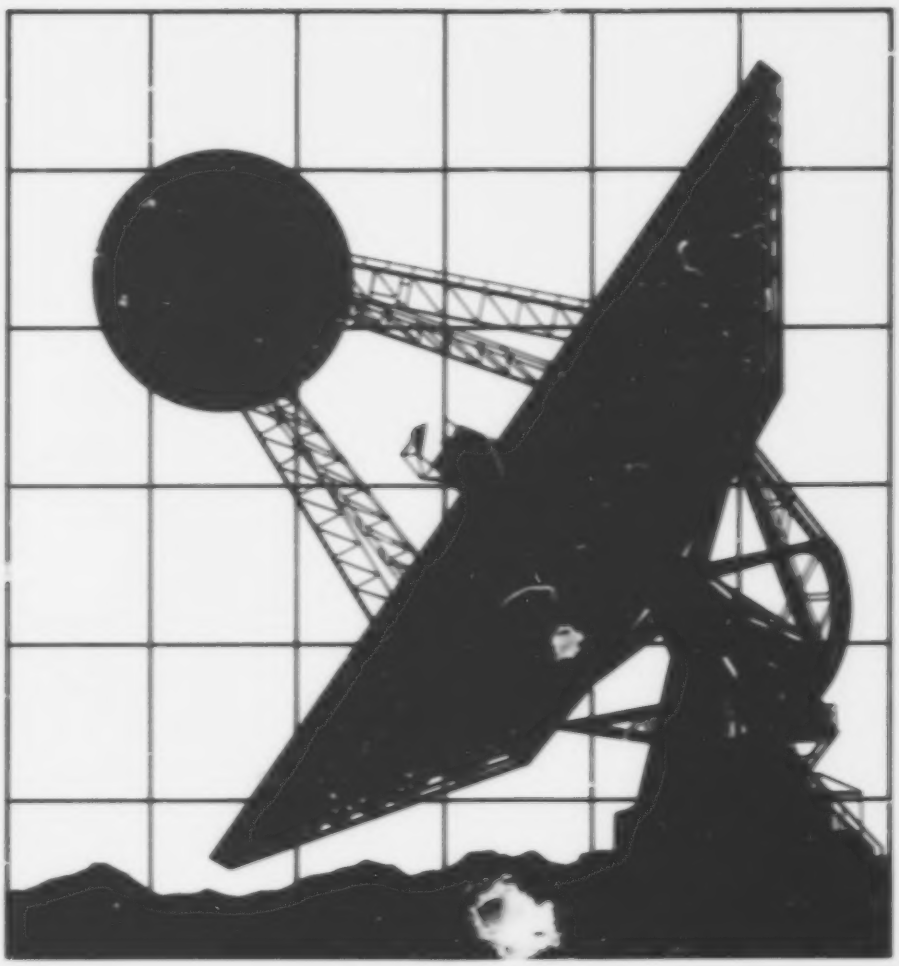

THE

DEEP SPACE NETWORK

For nearly three decades, the scientific investigation of the solar system has been carried out by the National Aeronautics and Space Administration (NASA) mainly through the use of unmanned automated spacecraft. These highly sophisticated exploring machines have sent back wondrous and surprising new information about Mercury, Venus, Mars, Jupiter, Saturn, Uranus, and, in 1989, Neptune. None of these missions of discovery would be possible, however, without the Deep Space Network, which provides the Earth-based radio communications link for all of NASA's unmanned interplanetary spacecraft.

The NASA Deep Space Network is the largest and most sensitive scientific telecommunications and radio navigation network in the world. Its principal responsibilities are to support unmanned interplanetary spacecraft missions and to support radio and radar astronomy observations in the exploration of the solar system and the universe. The Network is a separate facility of the NASA Office of Space Operations and is managed, technically directed, and operated by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena, California.

The precursor of the Network was established in January 1958 when JPL, under contract to the U.S. Army, deployed radio tracking stations in Nigeria, Singapore, and California to support the first successful U.S. satellite, Explorer 1. NASA was officially established on October 1, 1958. On December 3, JPL was transferred to NASA and given responsibility for unmanned lunar and planetary exploration programs. Shortly afterward, NASA established the concept of the Deep Space Network as a separate Earth-based communications facility that would support many space flight missions simultaneously, thereby avoiding the impractical duplication of a specialized space communications network for each flight project. The Network was given responsibility for its own research, development, and operation in support of all its users. Under this concept, it has become a world leader in the development of low-noise receivers, tracking, telemetry, and command systems, digital signal processing, and deep space radio navigation. These functions are incorporated in a state-of-the-art telecommunications system that can be upgraded to meet the requirements of new missions while maintaining support for current missions.

The Network currently consists of 12 deep space stations positioned at three Deep Space Communications Complexes, which are located on three continents: at Goldstone in Southern California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The Network Operations Control Center, which controls and monitors operations at the three complexes, is located at JPL in Pasadena. The Network's Ground Communications Facility provides and manages the communications circuits that link the complexes, the control center in Pasadena, and the remote flight project operations centers together.

The unmanned space flight projects supported by the Network are managed and controlled by the NASA Office of Space Science and Applications or by foreign space agencies. The Network's responsibilities are to receive the telemetry signals from the spacecraft, to

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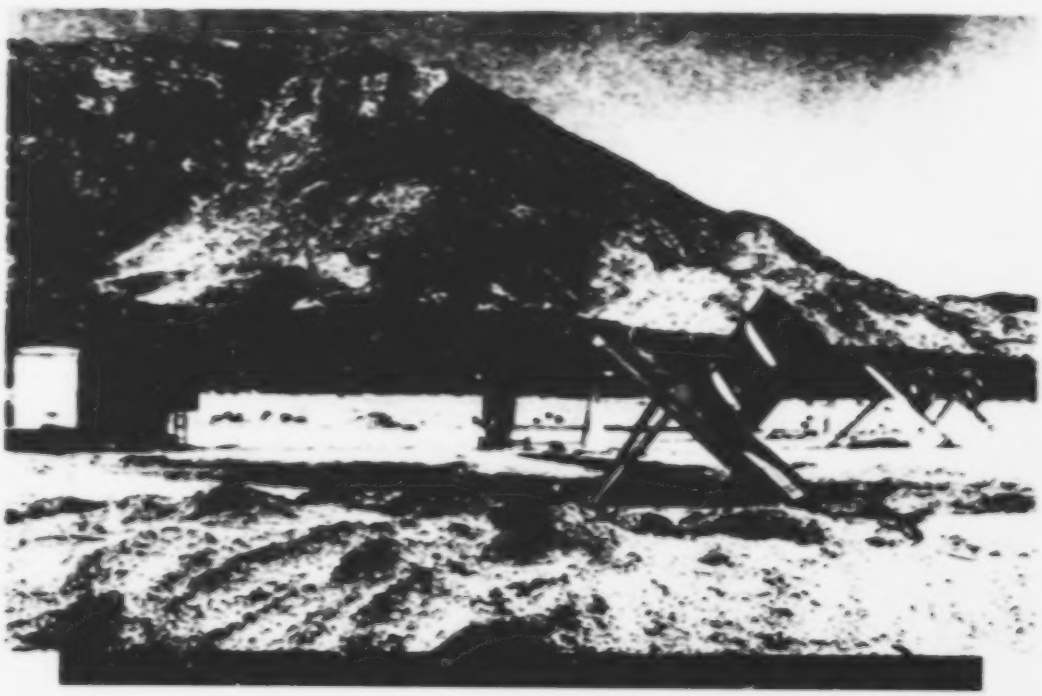
transmit commands that control the spacecraft operating modes, and to generate the radio navigation data that are used to locate and guide the spacecraft to its destination. The Network is also used for flight radio science, radio and radar astronomy, very long baseline interferometry, and geodynamics measurements, and will be a major participant in NASA's Search for Extraterrestrial Intelligence.

The Network staff in the United States consists of JPL engineering and technical personnel assisted by contractor engineers and technicians who are primarily responsible for operating and maintaining the Goldstone complex, the Network Operations Control Center, and the Ground Communications Facility at JPL. The Spanish and Australian complexes are staffed and operated by agencies of the Spanish and Australian governments and their contractors. The total international Network staff numbers over 1100 people.

The Deep Space Communications Complexes are located at Goldstone, California; near Madrid, Spain; and near Canberra, Australia.

In 1958, JPL's Microlock system, the Deep Space Network's precursor, used 5-foot-long helical antennas to track the flight of Explorer 1, the first successful U.S. satellite.



The 26-meter (85-foot) diameter antenna tracks scientific and communications satellites, which orbit the Earth at altitudes ranging from 240 to 36,000 kilometers (150 to 22,500 miles).

DEEP SPACE COMMUNICATIONS COMPLEXES

Every U.S. deep space mission is designed to allow continuous radio communication with the spacecraft. Continuous 24-hour coverage for several spacecraft requires several Earth-based stations at locations that compensate for the Earth's daily rotation. The locations in Spain, Australia, and California are approximately 120 degrees apart in longitude, which ensures continous observation and suitable overlap for transferring the spacecraft radio link from one complex to the next.

The Australian complex is located 40 kilometers (25 miles) southwest of Canberra near the Tidbinbilla Nature Reserve. The Spanish complex is located 60 kilometers (37 miles) west of Madrid at Robledo de Chavela. The Goldstone complex is located on the U.S. Army's Fort Irwin Military Reservation, approximately 72 kilometers (45 miles) northwest of the desert city of Barstow. Each complex is situated in semi-

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mountainous, bowl-shaped terrain to shield against radio frequency interference.

Each complex consists of four deep space stations equipped with ultrasensitive receiving systems and large parabolic dish antennas. There are two 34-meter (111-foot) diameter antennas, one 26-meter (85-foot) antenna, and one 70-meter (230-foot) antenna. In Canberra and Madrid, the 70-meter antennas were recently extended from their original 64-meter diameters in preparation for the Voyager 2 spacecraft encounter with Neptune in 1989. Extension of the 64-meter antenna at Goldstone will be completed in June 1988. One of the 34-meter antennas at each complex is a new design, high-efficiency antenna that provides improved telemetry performance needed for outer-planet missions.

The 34- and 70-meter stations are remotely operated from a centralized Signal Processing Center, which houses the electronic subsystems that point and control the antennas, receive and process the telemetry, generate and transmit commands, and produce the spacecraft navigation data. All of these activities are performed at the processing center by a six-person crew. The 26-meter stations have not yet been equipped for remote operation.

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The Goldstone Deep Space Communications Complex is located in Southern California's Mojave Desert, approximately 160 kilometers (100 air miles) northeast of Pasadena.

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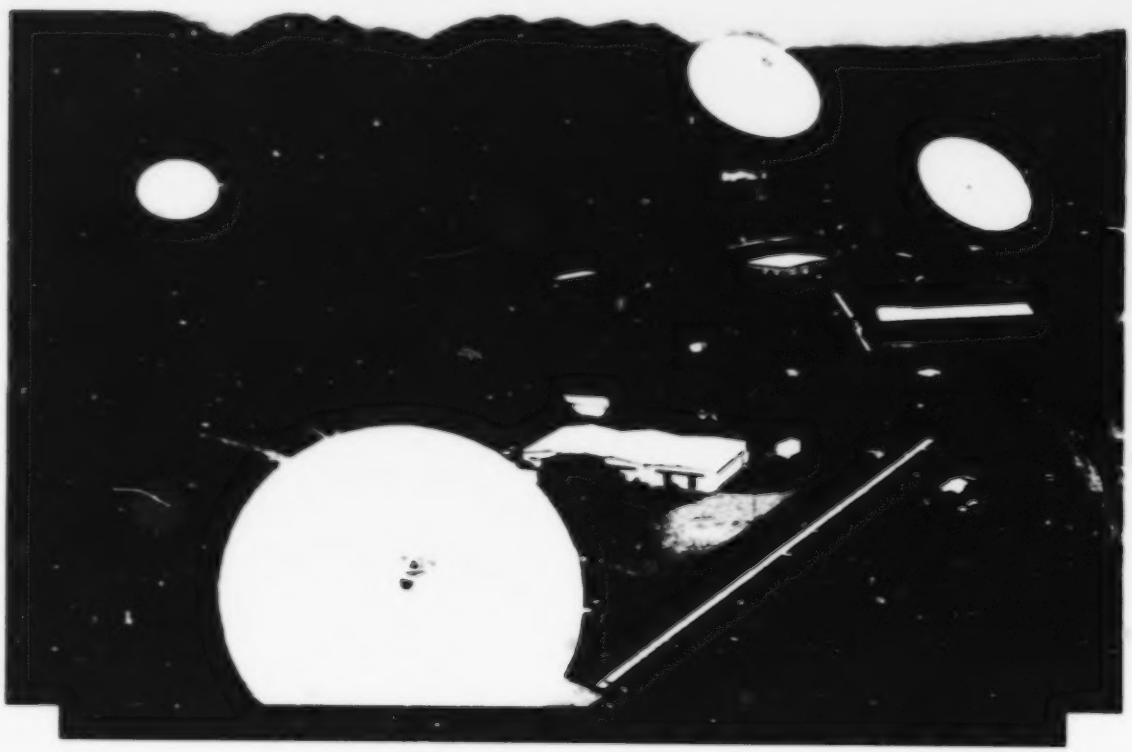
The antenna sizes form separate subnets, which have different communications capabilities. The 70-meter antenna subnet, which is the most sensitive, supports deep space missions; the 26-meter subnet supports spacecraft in Earth orbit; and the two 34-meter subnets support both types of missions. The 26-meter antenna stations were originally part of the Spaceflight Tracking and Data Network, which is operated by NASA's Goddard Space Flight Center. The Goddard network is designed to support the manned orbiting Shuttle flights and Earth-orbiting scientific and communications satellites. The 26-meter stations were consolidated into the Deep Space Network in 1985 when it assumed an important added tracking responsibility for spacecraft in high elliptical Earth orbits. This realignment was in anticipation of the activation of Goddard's new Tracking and Data Relay Satellite System, which is not compatible with spacecraft in "high" Earth orbits that travel out beyond the range of the new relay satellite system. This system will eventually replace nearly all of Goddard's ground stations, leaving the Deep Space Network as NASA's only ground station network.

Right: The 34-meter (111-foot) standard antenna, originally 26 meters (85 feet) in diameter, was the first antenna erected at each complex during the 1960s. It is patterned after radio astronomy antennas then in use in the United States. The extension to 34 meters was implemented in 1978–79.

The Madrid complex is 60 kilometers (37 miles) west of Madrid in the El Escorial region of central Spain.



The Canberra complex in Australia is 40 kilometers (25 miles) southwest of Canberra near the Tidbinbilla Nature Reserve.

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NETWORK OPERATIONS CONTROL CENTER

The Control Center, which is the operations hub of the Network, is located at JPL in Pasadena. Its functions are to monitor operations at the three complexes, to analyze and validate the performance of the Network for flight project users, to provide information for configuring and controlling the Network, and to participate in Network and mission testing.

GROUND COMMUNICATIONS FACILITY

The Ground Communications Facility provides and controls the communications circuits that link the three complexes to the control center at JPL and to the flight project control centers in the United States and overseas. The communications traffic between these various locations is sent via land lines, submarine cable, terrestrial microwave, and communications satellites. These circuits are leased from common carriers and provided to the Facility as needed by the NASA Communications Network, which is located at the NASA Goddard Space Flight Center. Spacecraft data sent over these lines are automatically

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The Network's Ground Communications Facility uses land lines, microwave links, submarine cables, and communications satellites to link the elements of the Network together.

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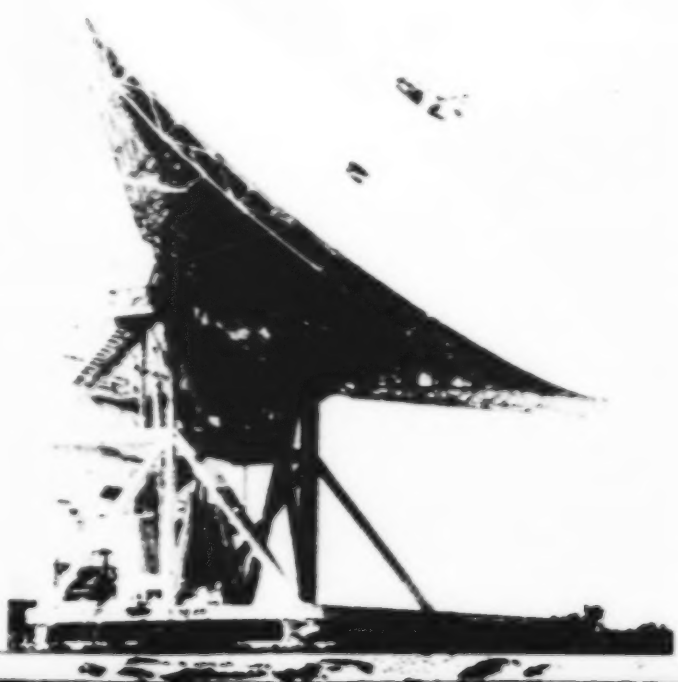
checked for transmission errors and outages by error detecting and correcting techniques, which automatically retransmit any data block received with a transmission error.

COMPATIBILITY TESTING

The Compatibility Test Area at JPL is used to verify the radio link with the spacecraft and to test the data message compatibility between the spacecraft, the Network, and a project control center. There is also a launch support and compatibility testing facility at the Kennedy Space Center launch site in Florida.



The new-design 34-meter high-efficiency antenna was added to the Goldstone complex in 1984, Canberra in 1985, and Madrid in 1987. The dish surface is "beam-shaped" for maximum signal-gathering efficiency.

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From 1958 through 1987, the Network has provided support to 25 space flight projects involving a total of 66 unmanned Earth-orbiting, lunar, and planetary spacecraft. Moon exploration began with the Pioneer 3 and 4 lunar probes (1958), followed by the Ranger 1–9 lunar TV probes (1961–65), the Surveyor 1–7 lunar landers (1966–68), and the Lunar Orbiter 1–5 photo survey for Apollo landing sites (1966–67).

Support for inner-planet exploration began in 1962 with JPL's Mariner series of missions to Venus, Mars, and Mercury, which involved six planetary flyby missions and the first planetary orbiter mission to Mars (1971). Concurrent with the Mariner flights were the NASA Ames Research Center Pioneer missions, beginning with the Pioneer 6–9 heliocentric orbiters (1965–68).

Support for the first outer-planet missions, the Pioneer 10 and 11 flybys of Jupiter and Saturn, began in 1972–73. The successful Pioneer 12 and 13 Venus orbiter and atmospheric multiprobe missions were initiated in 1978. During the late 1960s and early 1970s, the Deep Space Network also provided backup communications support for the manned Apollo missions to the Moon.

In the mid 1970s, the Network began support for the Helios 1 and 2 solar orbiters, a joint American–West German project to investigate the near-solar environment, and the NASA Langley Research Center's Viking 1 and 2 Mars orbiter and lander missions. In 1977, JPL's Voyagers 1 and 2 began their outer-planet flyby missions to Jupiter (1979), Saturn (1980), Uranus (1986), and Neptune (1989).

During 1980–87, the Network provided support to the following deep space and Earth-orbiting missions:

- *Pioneers 6 through 8.* In heliocentric orbits between Venus, Earth, and Mars, Pioneers 6, 7, and 8 are returning solar weather data. Pioneer 6, launched in December 1965, is the world's oldest operating spacecraft. The signal from Pioneer 9 was lost in 1983.
- *Pioneers 10 and 11.* These spacecraft are returning scientific data from the previously unexplored outer edges of the solar system. Pioneer 10 will be the first Earth-made object to leave the solar system.

- *Pioneer 12.* In Venus orbit, Pioneer 12 is returning Venusian atmospheric data. The spacecraft was used to observe Halley's comet in early 1986.

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- *Voyagers 1 and 2*. In January 1986, Voyager 2 encountered Uranus and was supported during the encounter with an international multistation array. The Deep Space Network is now preparing for the Voyager 2 encounter with Neptune in 1989, and will eventually track both Voyagers beyond the solar system and into interstellar space.

- *Nimbus 7*. This low-polar-orbiting weather satellite is used for oceanography and pollution monitoring.

- *International Venus Balloon and Pathfinder Mission*. The Venus Balloon Experiment involved two Soviet Vega spacecraft, each carrying a French meteorological balloon that was inserted into the Venusian atmosphere as the two spacecraft passed the planet on their way to a flyby of Halley's comet. The Deep Space Network and an international array of 17 other antenna stations successfully tracked the balloons, providing information on the weather dynamics of the Venusian atmosphere.

- *Halley's Comet Flyby*. The Network provided navigation support to five international spacecraft that encountered Halley's comet in March 1986. The Halley flyby involved Soviet Vega 1 and 2 spacecraft, the Japanese Sakigake and Suesei spacecraft, and the European Space Agency's Giotto spacecraft.

- *International Cometary Explorer*. The Madrid and Goldstone complexes maintained continuous communication with the International Cometary Explorer as it passed through the tail of the Giacobini-Zinner comet in September 1985. Support was also provided by the Japanese Usuda observatory and the National Astronomy and Ionosphere Center's Arecibo Observatory in Puerto Rico. The Deep Space Network and the Usuda observatory continued support for the Explorer during its observations of Halley's comet in December 1985 and March 1986. The Network will continue support until the end of the mission in 1988.

Far left: The Network Operations Control Center at JPL in Pasadena monitors and controls operations at the three Network complexes in California, Spain, and Australia.

The Deep Space Network has been tracking unmanned spacecraft since 1962.

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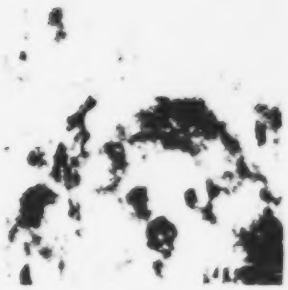

July 1965: Mariner 4; Mars
Data rate: 8⅓ bits/s
Range: 12,500 km (7,800 mi)
Distance to Earth: 216 million km (134 million mi)

January 1972: Mariner 9; Mars, Olympus Mons
Data rate: 16,200 bits/s
Range: 2,500 km (1,600 mi)
Distance to Earth: 0.5 to 2.5 AU

July 1976: Viki Orbiter; Mars, dioxide atmos
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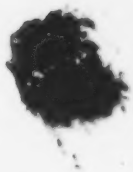

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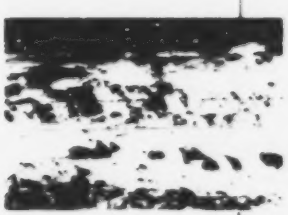
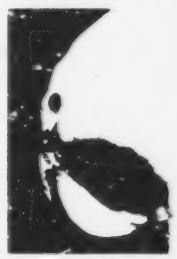
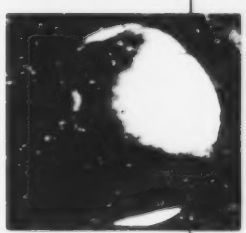


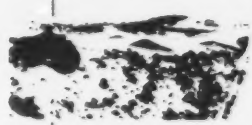
November 1966: Lunar Orbiter 2; Moon, approaching Copernicus Crater
Data rate: 50 bits/s
Range to surface: 72 km (45 mi)
Distance to Earth: 378,000 km (238,829 mi)

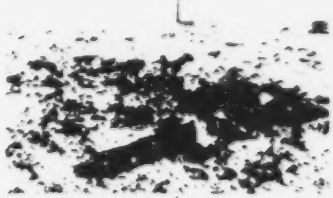
February 1974: Mariner 10; Venus, cloudy rotating atmosphere
Data rate: 117,600 bits/s (experimental)
Range: 720,000 km (450,000 mi)
Distance to Earth: 9.3 AU



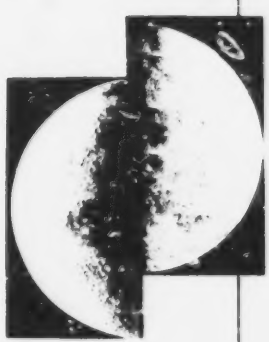


August 1969: Mariner 7; Mars, showing ice caps
Data rate: 16,200 bits/s
Range: 375,000 km (230,000 mi)
Distance to Earth: 0.7 AU





January 1968: Surveyor 7; Moon, near Tycho Crater
Data rate: 1100 bits/s
Distance to Earth: 375,000 km (233,000 mi)



March 1974: Marin 10; Mercury
Data rate: 117,600 bits/s (experimental)
Range: 200,000 km (125,000 mi)
Distance to Earth: 1 AU

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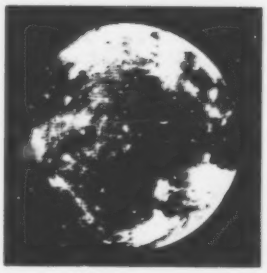
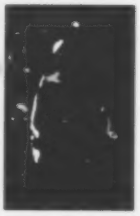
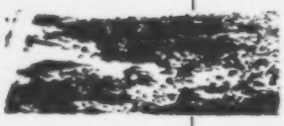


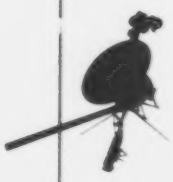
March 1979: Voyager 1; Jupiter moon Ganymede
Data rate: *115,000 bits/s*
Range: *2.6 million km (1.6 million mi)*



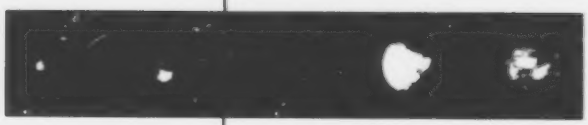
July 1979: Voyager 2; Jupiter moon Io, volcanic eruptions
Data rate: *115,000 bits/s*
Range: *1.2 million km (744,000 mi)*



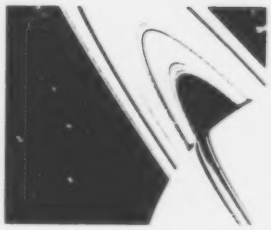
July 1976: Viking 1 Lander; Martian dune field
Data rate: *16,000 bits/s*
Distance to Earth: *0.5 to 2.5 AU*



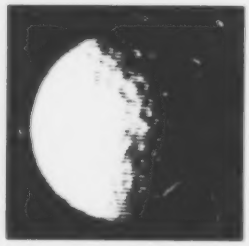
March 1979: Voyager 1; Jupiter and satellites
Data rate: *115,000 bits/s*
Range: *20 million km (12 million mi)*
Distance to Earth: *5 AU*



January 1986: Voyager 2; Uranus' moons
Data rate: *29,900 bits/s*



August 1981: Voyager 2; Saturn ring system
Data rate: *44,800 bits/s*
Range: *22 million km (14 million mi)*
Distance to Earth: *10 AU*



November 1980: Voyager 1; Saturn moon Mimas
Data rate: *44,800 bits/s*
Range: *425,000 km (264,000 mi)*

January 1986: Voyager 2; Uranus moon Miranda
Data rate: *29,900 bits/s*
Range: *36,000 km (22,000 mi)*
Distance to Earth: *20 AU*

January 1986: Voyager 2; Uranus ring system
Data rate: *29,900 bits/s*
Range: *7.7 million km (4.8 million mi)*

November 1980: Voyager 1; Saturn and satellites
Data rate: *44,800 bits/s*
Range: *13 million km (8 million mi)*
Distance to Earth: *10 AU*

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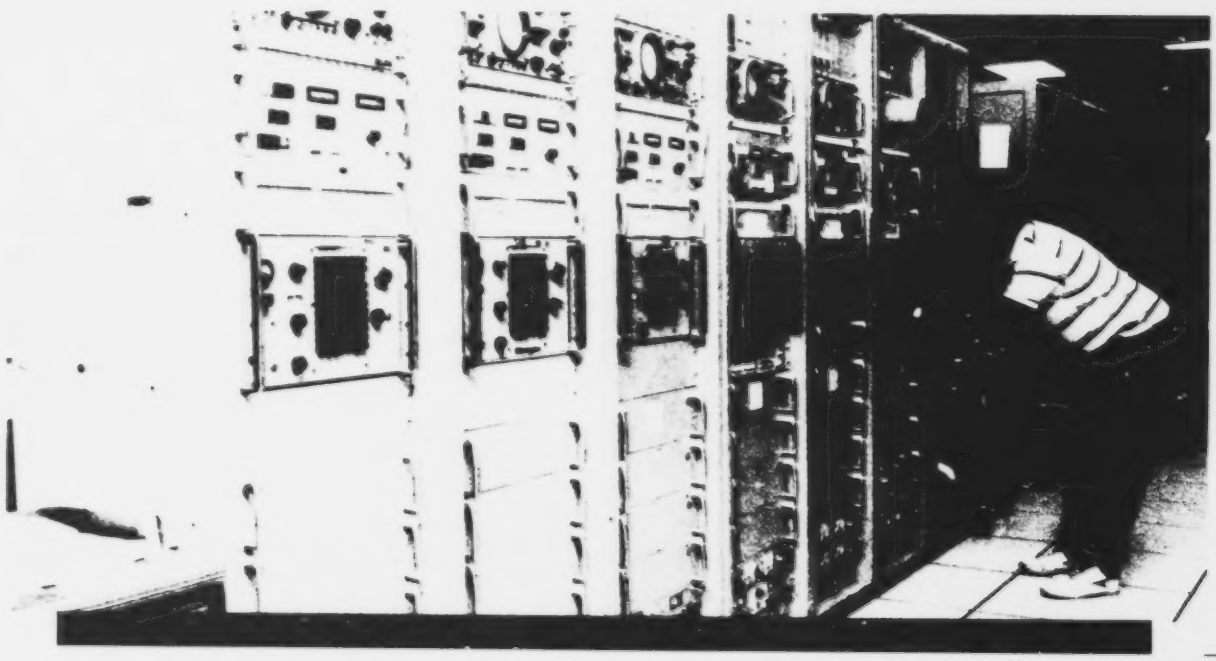
- *Active Magnetospheric Particle Tracer Explorers (AMPTE).* AMPTE involved three spacecraft in Earth orbit that periodically released barium and lithium particles into the Earth's magnetosphere in 1984 and 1985 for a study of the interaction between the magnetosphere and the solar wind. Two of the three spacecraft have completed their missions.
- *International Sun–Earth Explorers 1 and 2.* These Earth-orbiting spacecraft investigated solar effects on the Earth's immediate space environment. Both spacecraft re-entered the Earth's atmosphere in September 1987.

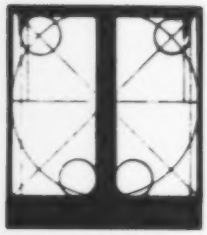
In addition, many geosynchronous spacecraft launched by various U.S. agencies and foreign governments are supported during their launch and transfer orbit phases.

Beginning in July 1988, the Network will support Phobos, two Soviet spacecraft missions that will place landers on the Martian moon Phobos. Scheduled for 1989 are Magellan, which will use radar to map 90 percent of the densely clouded surface of Venus, and Galileo, the Jupiter orbiter–probe mission. The European Space Agency's Ulysses, a solar environment explorer, is scheduled for launch in 1990, and Mars Observer, which will conduct an extended study of the Martian system, is scheduled for 1992.

Facing page: The 70-meter antenna extension under construction at Goldstone in late 1987.

Receivers, demodulators, processors, etc., recover the telemetry and navigation data from the spacecraft signal. The "raw" telemetry is sent via worldwide circuits directly to the flight project control centers in the United States, Europe, or Japan.





The single factor that makes a deep space communications system different from other radio systems is the distance involved. The Network currently maintains direct radio links with spacecraft that are now approaching the edge of the solar system. After traveling across the overwhelming vastness of interplanetary space, the spacecraft signal that reaches the Earth ranges in power from a billionth of a watt down to a billionth of a trillionth of a watt. The main technology elements that make it possible to receive, amplify, and extract scientific data from such ultraweak signals are the use of high microwave radio frequencies (2110–2300 and 8400–8450 megahertz), an optimum energy-per-bit telemetry scheme, and the state-of-the-art sensitivity and efficiency of the Network antennas and low-noise receiving systems.

During the relatively brief time span since the beginning of space exploration, exceptional progress has been made in improving the quantity and quality of scientific data returned from each planetary mission. As an example, in 1965, the Mariner 4 flyby mission to Mars produced the first television images of another planet's surface. Because of the Earth–Mars distance—a then-record 216 million kilometers (134 million miles)—the spacecraft data transmission rate was limited to 8⅓ bits per second, requiring about 8 hours to return one 240,000-bit image. The best television performance obtained was a total of 22 coarsely defined digital images that roughly showed only a small narrow strip of the planet's surface—a first-ever scientific feat that was remarkable for its time.

By 1974, during the Mariner 10 flyby mission to Venus and Mercury, the Network successfully received experimental transmissions at a data rate of 117,600 bits per second (117.6 kilobits), which provided, at first opportunity, nearly a total high-resolution map of the sunlit side of Mercury at an Earth–Mercury distance of 158 million kilometers (98.7 million miles).

To achieve this ten-thousandfold improvement in approximately 9 years, both the spacecraft and the Network have undergone significant evolutionary improvements. Each spacecraft, when launched, has a fixed communications capability and a finite lifetime. The Network, as an ongoing facility, must continuously improve and upgrade its capabilities to accommodate in-flight changes to the science objectives of current missions and to meet the navigation and telemetry requirements of future missions. The main objective in this evolution is to improve the scientific data return by increasing the data transmission rate and navigation accuracy.

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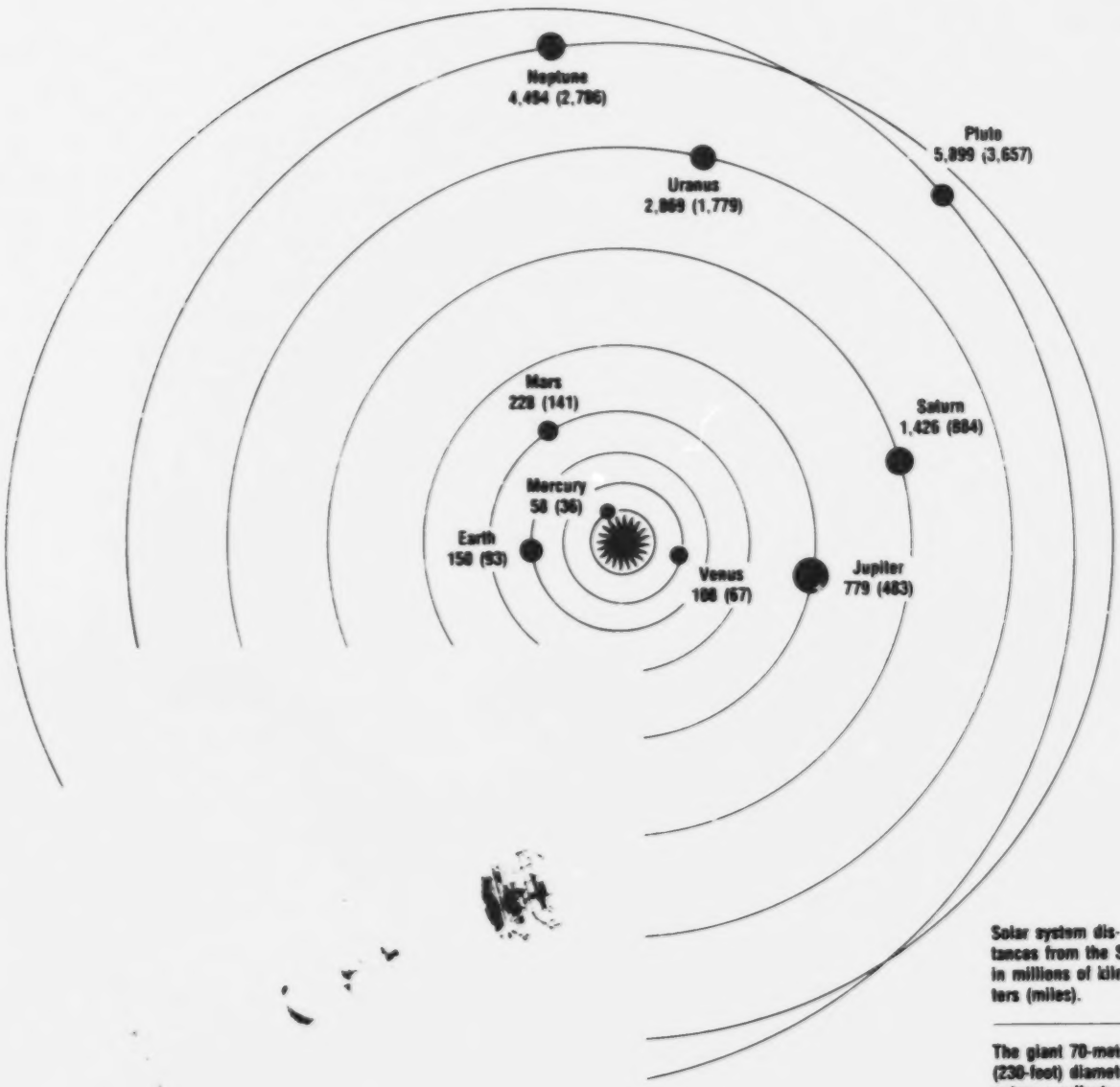
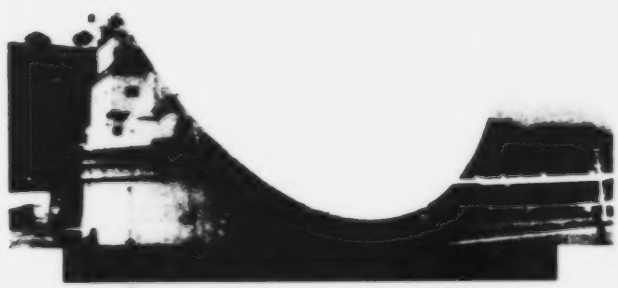


Solar system distances from the Sun in millions of kilometers (miles).



The giant 70-meter (230-foot) diameter antenna collects and amplifies spacecraft radio signals as weak as a billionth of a trillionth of a watt. The overall height is 71 meters (234 feet) and the total weight including the concrete pedestal is 7262 metric tons (8000 U.S. tons).

To date, the most challenging and technologically complex missions supported by the Network have been the Voyager 1 and 2 missions to the outer planets. The objective was to investigate the Jupiter and Saturn planetary systems and the interplanetary medium between Earth and Saturn.

The twin spacecraft, launched in 1977, are the most versatile yet to be flown. At encounter with Jupiter in 1979, both transmitted at a data rate of 115,200 bits per second (115.2 kilobits) across a Jupiter–Earth communications distance of 700 million kilometers (435 million miles). Approximately 33,000 abundantly clear pictures were received by the Network at the rate of one 5-million-bit image every 48 seconds. Jupiter and its five satellites were revealed in sufficient close-up detail to discover a Saturn-like ring around the planet and active volcanoes on the satellite Io.

For the second half of the mission at Saturn, a spacecraft-to-Earth distance of 1.6 billion kilometers (1 billion miles), the spacecraft signal power received by the Network antennas would be reduced to one-fourth of the power received at the Jupiter distance. Consequently, the data rate for transmitting television images would also be reduced to approximately one-fourth, or 29 kilobits per second. During the 18-month cruise to Saturn, Network engineers carefully reviewed the ground receiving system, finding some areas where the sensitivity could be increased to accommodate a higher data rate. An experimental receiver technique,

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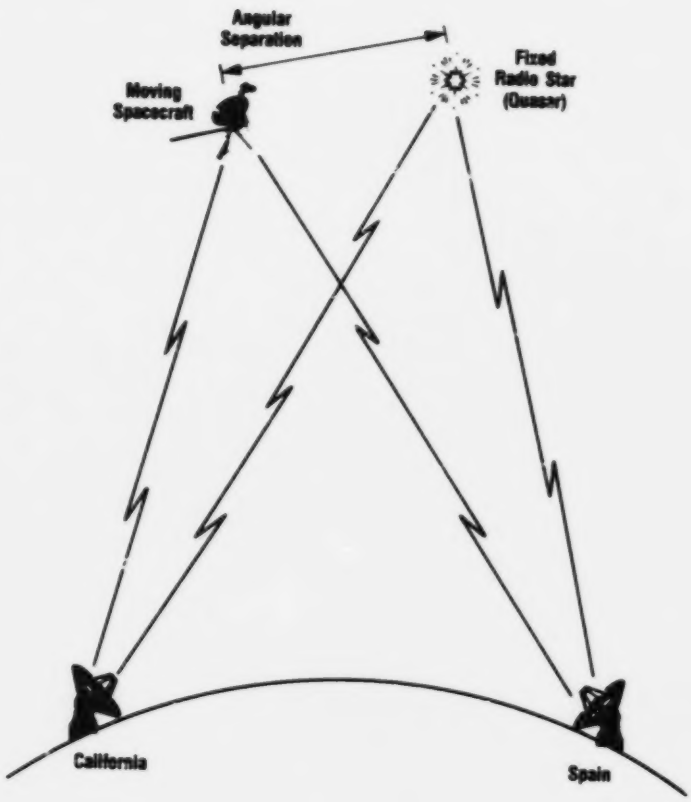
the arraying of joint 64- and 34-meter antennas, whereby the weak signals received at each antenna are combined into a single, stronger signal, was also implemented. During the Saturn encounter, these Network improvements enabled a 50-percent increase in the data rate to 44.8 kilobits per second, allowing pictures to be received at the rate of one every 2 minutes, 24 seconds. From both Voyagers 1 and 2, the Network successfully received approximately 30,000 high-quality television images of Saturn, its rings, and its 17 satellites. Further analysis of these images revealed the existence of four to six more tiny satellites.

Another Network contribution to the success of the Saturn encounter was the demonstration of a new radio navigation technique called differential very long baseline interferometry, which was used experimentally to augment the conventional Doppler and ranging navigation technique. The interferometry technique uses two widely separated Network stations on different continents (California–Australia or California–Spain) to simultaneously receive signals from the spacecraft and from an angularly nearby natural radio source (quasar), whose celestial coordinates are very well known. The data taken by the two stations are then correlated to provide a precise measurement of the angular separation between the spacecraft and the quasar. These experimental measurements proved to have a repeatable precision of approximately 50 nanoradians (an angular measurement in billionths of a degree) or 5 to 10 times the angle measurement accuracy of the Doppler and range technique.



Facing page: The Voyager spacecraft.

Very long baseline interferometry radio navigation. Approximately 100 extragalactic natural radio sources serve as fixed reference points for spacecraft navigation.

Voyager 1 preceded Voyager 2 through the Saturn system by 9 months, which allowed Voyager 1 science results to be used in planning the Voyager 2 encounter. One of the primary scientific objectives was to navigate Voyager 1 first to encounter the satellite Titan, then behind Saturn and its rings so that radio transmission, altered by passing through the planet's atmosphere and through the rings, would

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provide scientists with information about the composition of the atmosphere and the size and structure of the ring material. That Voyager 1 crossed the ring plane and successfully passed through the Saturn system without catastrophically colliding with any of the ring material made it possible to select a different trajectory for Voyager 2. Voyager 1 departed Saturn on a fixed flight path, rising above the plane of the solar system to investigate magnetic fields and charged-particle environments on its way to an exit of the heliosphere, the gigantic magnetic bubble that marks the edge of the solar system. After confirming the success of Voyager 1, NASA approved an extended planetary mission for Voyager 2 and a change in its trajectory that would send the spacecraft from Saturn to a flyby of Uranus in 1986 and Neptune in 1989.

The extension of the Voyager 2 mission beyond its original Jupiter–Saturn design meant that Network and Voyager engineers were facing still another severe decrease in signal strength and its limiting impact on science data return. At Uranus, a spacecraft-to-Earth distance of 3 billion kilometers (1.875 billion miles), the Voyager signal would drop to less than one-tenth of the power received during the Jupiter encounter, and at Neptune, 4.6 billion kilometers (2.875 billion miles) from Earth, to less than one-twentieth. The Voyager science requirements for Uranus were to obtain continuous general science data throughout the encounter period, and to obtain some 330 imaging observations during the near encounter that would provide a basic characterization of Uranus, its satellites, and its rings. For the several days immediately preceding and after the near encounter, approximately 300 images per day were desired. To meet these requirements, Network and Voyager engineers undertook a major redesign of the Voyager end-to-end data system with the goal of obtaining a science data return approaching that of the Jupiter and Saturn encounters. Studies by Voyager engineers resulted in the reprogramming of two of the six computers on board the spacecraft with an image data compression technique that allowed a 60-percent reduction in the number of bits needed to produce images with the quality obtained at Saturn. The time needed to transmit a single image would be 4 minutes, compared to 2 minutes, 24 seconds at Saturn and 48 seconds at Jupiter. Without the data compression technique, each picture would take nearly 13 minutes in the data stream, severely limiting the number that could be returned.

Facing page: The Australian government's 64-meter (210-foot) diameter radio telescope at Parkes cooperatively supported the Voyager encounter with Uranus in January 1986 by forming a four-element array with the Canberra complex 275 kilometers (170 miles) away. The added signal strength from Parkes contributed 410 Uranus images to the science data. Parkes will also support the Voyager–Neptune encounter in 1989.

Operations personnel at the complex Signal Processing Center remotely control and monitor the performance of the 70- and 34-meter antennas and the reception and processing of the spacecraft signal. Signals from three spacecraft can be received and processed simultaneously.

The spacecraft modification provided only part of the improvement needed to obtain the desired imaging data, leaving the remainder to be provided by the Network. Beginning in 1981, studies with respect to requirements for Voyager–Uranus, as well as other missions planned for the late 1980s to the early 1990s, led to the construction of a new-design 34-meter high-efficiency antenna at each complex. The new antenna would permit a three-element array, consisting of two 34-meter antennas and one 64-meter antenna. The data rate with the three-element array was calculated to be 19 kilobits per second, still below the rate needed to meet all of the imaging science requirements. To provide the maximum possible support for the Uranus and Neptune encounters, which cannot be attempted again in this century—literally a once-in-a-lifetime opportunity for many scientists—the Network investigated the feasibility of temporarily adding one or more adjacent antennas that belong to other scientific organizations. In Australia, the Network engineers conducted a study of the 64-meter Parkes radio telescope, which is located 275 kilometers (170 miles) from the Canberra complex.

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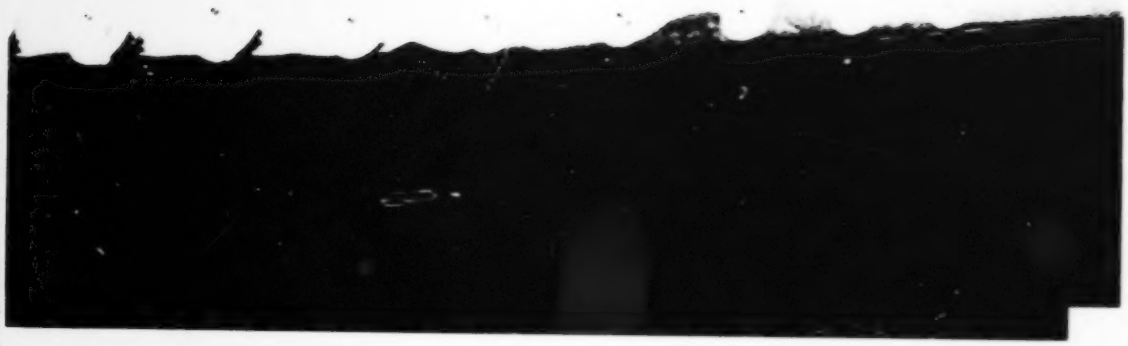

The National Radio Astronomy Observatory's Very Large Array at Socorro, New Mexico, will be arrayed with the Goldstone complex for the Voyager–Neptune encounter in 1989. The Array consists of twenty-seven 25-meter (82-foot) antennas in a Y-shaped configuration that operates as one single superlarge antenna.

The study concluded that the available Voyager data rates of 21.6 and 29.9 kilobits per second could be accommodated by adding the Parkes antenna to the array at Canberra via a ground microwave link. Arrangements were made with the Australian government to "borrow" the Parkes antenna for the Uranus and Neptune encounters, thereby establishing for the first time a cooperative interagency array for the support of a major planetary encounter. During the 4½-year cruise to Uranus, Network engineers designed, implemented, and installed the necessary receivers, signal combiners, and data recorders at Parkes and the Canberra complex. Beginning with initial observations on November 4, 1985, through the 6-hour close encounter on

January 24, 1986, and ending on February 24, 1986, the Network acquired a total of 2516 images of Uranus, its rings, and its five satellites, revealing fascinating and unique surface features and details of the satellites and the ring system, seen for the first time since the discovery of Uranus 205 years ago.

For the 1989 Voyager encounter with Neptune, which is 1.6 billion kilometers (1 billion miles) beyond Uranus, the Network plans to provide the same quantity and quality of images that were obtained at Uranus. A major improvement now under way will be the completion of the 70-meter antenna at Goldstone, and reshaping the dish surface to improve its efficiency. The effective signal capture of the 70-meter antenna will be 1½ times that of the 64-meter antenna. In addition to the Canberra–Parkes array in Australia, a new interagency array will be established between the Goldstone complex in California and the National Radio Astronomy Observatory's Very Large Array in New Mexico. The Array consists of twenty-seven 25-meter antennas that can be moved in position along three Y-shaped radial tracks. The effective combined output of the 27 antennas will be the equivalent of 2½ Network 70-meter antennas. The Array will be connected to Goldstone by either a ground microwave link or by communications satellite. These improvements will allow a 21.6-kilobit data rate from Voyager 2 at Neptune.

The Network operates 24 hours a day, 7 days a week.

With most of the heliosphere as well as the interstellar space before them, Voyagers 1 and 2 will continue to provide new and important scientific information for several years.

The Deep Space Network is a continuously evolving state-of-the-art telecommunications network. Future capabilities that will make later space exploration objectives feasible and scientifically richer are always in progress. This brochure, in effect, is a snapshot of the Network's facilities and capabilities as of January 1988.

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